EQUIPMENT

UDC 666.3.032.6

DETERMINATION OF THE OPTIMAL PRODUCTIVITY OF A SCREW CONVEYOR VACUUM-PRESS FOR MOLDING CERAMIC GREEN MIXES

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Translated from *Steklo i Keramika*, No. 1, pp. 30 – 33, January, 2010.

The determination of the optimal productivity of a screw conveyor vacuum-press molding articles from ceramic green mixes is analyzed. Different variants of productivity determination taking account of the motion of porcelain mix in the press channels and its physical – mechanical properties are presented.

Key words: ceramic, production, green mix, vacuum-press, productivity, calculation.

Green mix becomes enriched with air during fine milling of stony and softening of clayey materials in the production of ceramics. The presence of air degrades the molding properties of the mix and affects press productivity, so that it becomes necessary to pre-degas the mix in a screw conveyor vacuum-press. The productivity of a screw conveyor vacuum-press depends on a number of factors: its geometric parameters, the physical – mechanical properties of the ceramic green mix being molded, the rotation rate of the screw, the shape of the articles being molded, the specific pressing pressure, the initial (nominal) gap between the expressing blade of the screw and the cylinder lining jackets, and so on.

Until now the large number of interfering factors and the lack of theoretical relations for some of them have made it impossible to develop a unified method for determining theoretically the productivity of a screw conveyor vacuum-press, which is very important to do for production.

The SNK-325 press is used in domestic and foreign press-construction practice. This press is equipped with a mechanism for regulating the gap between the edge of a screw blade and the cylinder jacket; this has increased the productivity of the press [1].

The driver of a screw press can be calculated if the productivity is represented as being the result of the interactions of three flows of the ceramic green mix in the working channels of such a press.

The translational motion of the ceramic green mix in the cylinder of the press arises as result of its being pushed by the frontal surface of a screw blade. Over one turn of the screw the mix moves over a distance equal to the pitch of the screw (Fig. 1).

It is known from practice that when the edge of a screw blade and the cylinder jacket becomes worn ceramic mix flows under the pressure gradient through the blade edge in a direction opposite to the axial motion of the mix in the cylinder [2]. This so-called “leakage flow” will be all the greater, the larger the gap between the blade edge and the surface of the cylinder and the larger the pressure difference on both sides of the screw blade (Fig. 2).

Thus, the following basic mix flows are observed in the driver of the screw press during molding of the material:

forward flow Q_{fw} produced by the pushing power of the frontal surface of the screw blades;

backward flow Q_{bw} caused by the pressure from the side of the press head and the motion of the screw blade surfaces in the opposite direction (as a rule a backward flow in the di-

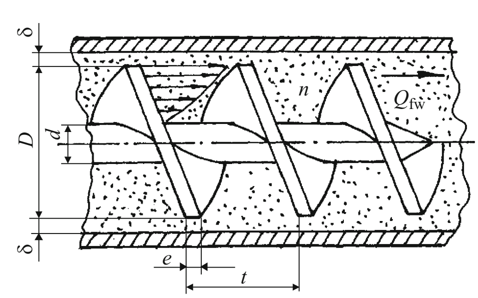

Fig. 1. Working channel of the forward flow of the green mix.

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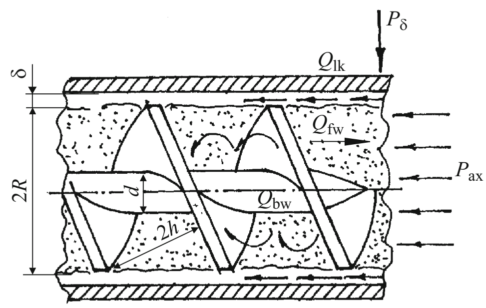

Fig. 2. Leakage flow of the mix, depending on the pressure difference between the mix flows in the press channel.

rect sense does not exist; it is manifested in the checking influence on the forward flow [1]);

leakage flow Q_{lk} caused by the pressure difference between both sides of a screw blade in the annular channel along the perimeter of a blade.

In general, taking account of all flows the productivity of a screw conveyor vacuum-press is described by the equation:

$$Q = Q_{fw} - Q_{bw} - Q_{lk}\,. \tag{1}$$

The value of these parameters can be written as follows.

The forward flow:

$$Q_{fw} = \frac{\pi(D^2 - d^2)tn}{4 \times 60},\ \mathrm{m^3 \cdot sec^{-1}},$$

where D is the diameter of the expressing blade, m; d is the diameter of the shaft of the screw, m; t is the pitch of the screw line of the screw, m; n is the rotation speed of the screw shaft, min^{-1}.

The backward flow:

$$Q_{bw} = \frac{\pi(D+d)Lhn}{60} + \frac{\psi}{(l+\psi)\mu_1}\left(\frac{K_\delta P_{ax}}{S}\right)^q L\,2h^{q+2},$$

where L is the distance from the screw shaft to the cylinder jacket, m; $2h$ is the pitch of the screw line of the screw shaft, m; ψ is the index of the mix flow, which is 0.1 – 0.3; μ_1 is the viscosity, μ_1 = 0.05 – 0.15 MPa · sec; q is the specific characteristic of the mix flow index; K_δ is the lateral pressure coefficient; P_{ax} is the axial pressure of the mix, Pa; S is the length of the screw channel in the cylindrical part of the press channel; and, l is the length of the action path of the axial pressure on the mix, m.

The leakage flow:

$$Q_{lk} = \frac{\pi Rtn\delta}{60} - \left(\frac{P_{ax}}{l}\right)^q \frac{\psi}{\mu_1^q(1+\psi)}\,\frac{\pi R\delta^{q+2}}{1+2\psi},$$

where R is the radius of a screw blade, m, and δ is the distance between a screw blade and the cylinder jacket, m.

Substituting the values of the parameters Q_{fw}, Q_{bw}, and Q_{lk} into Eq. (1), having first projected on the horizontal axis of the screw, the rates of the flows of the ceramic green mix in the screw channels, we obtained the relation [1]

$$Q = \frac{\pi(D^2 - d^2)tn}{240} - \frac{t}{2\pi R}\left[\frac{\pi(D+d)Lhn}{60} + \frac{\psi}{\mu_1^q(1+\psi)}\left(\frac{K_\delta P_{ax}}{S\cos\beta}\right)^q L2h^{q+2}\right] + \frac{\pi Rtn\delta}{60} - \left(\frac{P_{ax}}{l}\right)^q \frac{\psi\pi R\delta^{q+2}}{\mu_1^q(1+\psi)(1+2\psi)}, \tag{2}$$

where $\cos\beta$ is the projection of the slope angle of a turn of the screw on the horizontal axis.

The Eq. (2) can be represented in the simplified form

$$Q = \frac{KP}{\mu_e},$$

where K is the coefficient of the geometric shape of the head and the mouthpiece, called the "characteristic" of the shaping unit of the press; P is the pressure expended on overcoming the resistances in the channel; μ_e is the effective viscosity; $\mu_e = f(\bar{\gamma})$, where $\bar{\gamma}$ is the gradient of the velocity.

The Oswald – de Ville equation is most suitable for a mathematical description of this relation:

$$\mu_e = \mu_1(\bar{\gamma})^{\psi - 1} \tag{3}$$

or after taking the logarithm

$$\log \mu_e = (\psi - 1)\log\bar{\gamma} + \log\mu_1\,,$$

where μ_1 is the viscosity with velocity gradient $\bar{\gamma} = 1$.

The Eq. (3) describes the behavior of the plastic ceramic green mix in a simple mathematical form.

The productivity (Q, $\mathrm{m^3/sec}$) of a screw vacuum-press can be determined using a somewhat more accessible relation [3]:

$$Q = \pi n\left(\frac{D^2 - d^2}{4}\right)(t - e)(1 - \alpha)\,k_1 k_2 k_3 k_4\,, \tag{4}$$

where e is the thickness of a screw blade, m; α is the packing factor of the molded green mix; k_1 is the productivity loss factor due to the return of the mix in the gap between the screw blades and the cylinder jacket of the screw; k_2 is the influence factor for the lift angle of the median screw line of the screw; the factor k_3 takes account of the number of returns of the expressing blade of the screw; and, the factor k_4 takes account of the slipping of the mix along a screw blade.

If only simple calculations of the productivity of a specific press with definite parameters for concrete conditions (with known physical – mechanical parameters of the

molded mix and a definite shape of the article) are required, then the problem is easily solved — we substitute all required data into the relation (4).

When it is necessary to design a new screw conveyor vacuum press, the problem becomes much more complicated.

To design a screw conveyor vacuum press (as any other machine) it is necessary to take account of the requirements of the state standards and the technical conditions. GOST 6113-84E gives a series of diameters of the expression blade of the screw: 355, 400, 450, and 500 mm.

Deviations from the diameters indicated in the standards are allowed for experimental, laboratory machines or in certain other cases. For each ceramic green mix there exists an optimal rotation rate of the screw. It has been established that as the rotational speed increases the productivity of the press increases initially; then, after reaching a definite value, the productivity starts to decrease, even though the rotational speed of the screw continues to increase.

The dependence of the productivity of the vacuum-press with expressing blade diameter 450 mm on the rotational speed of the screw with different moisture content of the ceramic mix (neglecting other influential factors) is presented in Fig. 3 and Table 1.

These data correspond to the experimental investigations of a new press with the best initial parameters for molding normal (full-bodied) construction brick $F_1/F_2 = 4.5$ made of category 2 clays (average plasticity), i.e., with plasticity factor $K_{pl} = 1$. Figure 3 displays curves of the maximum values of the productivity for each value of the moisture content of the mix being molded from 16 to 24%. Intermediate values can be adopted by interpolation.

The investigations show that as the rotational speed of the screw shaft increases, the productivity increases only if the moisture content of the molded mix increases and decreases substantially if the moisture content decreases.

However, it should be remembered that to decrease the drying time of the half-finished product substantially the moisture content of the mix must be decreased. This dialectical contradiction must be resolved during the design process by optimizing the parameters of the press.

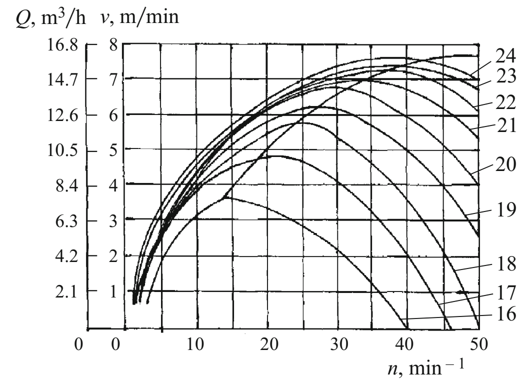

Fig. 3. Press productivity Q and mix output rate versus the rotational speed of the screw n with different moisture content of the mix; the numbers on the curves are the moisture content of the mix (%).

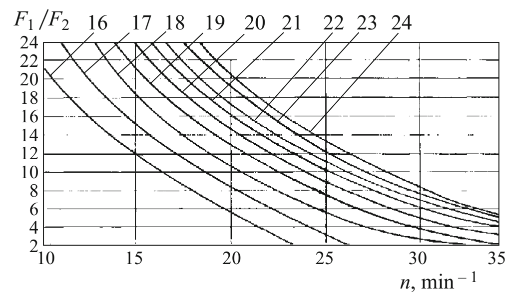

Fig. 4. Optimal rotational speed of the screw n versus the ratio F_1/F_2 with different moisture content of the green mix. The labeling of the curves is the same as in Fig. 3.

In addition, the data in Fig. 3 correspond to the ratio of the area of the expressing blade of the screw F_1 to the transverse section of the mouthpiece F_2 equal to 4.5 (for a normal full-bodied construction brick). For otherwise equal conditions, an increase of this ratio results in a decrease of the pro-

TABLE 1.

Moisture content, %	Press productivity, m^3/h, with screw rotational speed, min^{-1}								
	10	15	20	25	30	35	40	45	50
16	6.30	7.15	6.70	5.75	4.40	2.35	–	–	–
17	7.85	9.55	10.30	9.50	8.45	6.70	4.20	–	–
18	8.80	10.75	11.70	12.15	11.40	9.65	7.40	4.25	–
19	9.25	11.30	12.60	13.00	12.55	11.70	10.10	7.90	5.30
20	9.60	11.50	12.80	13.60	13.65	13.55	12.50	10.70	8.40
21	9.70	11.60	13.00	13.80	14.60	14.70	13.85	12.70	11.30
22	9.75	11.70	13.15	14.40	14.90	15.10	14.80	13.80	12.60
23	9.80	11.80	13.50	14.50	15.10	15.25	15.30	14.80	13.75
24	9.85	11.90	13.60	14.70	15.30	15.55	15.70	15.35	14.70

TABLE 2.

Ratio F_1/F_2	Optimal rotational speed of the screw shaft, min^{-1}, with moisture content of the molded mix, %								
	24	23	22	21	20	19	18	17	16
2	47.0	44.5	41.5	39.0	36.5	34.5	33.0	25.5	23.2
4	38.0	36.5	35.5	33.5	31.5	29.5	27.0	25.0	21.1
6	31.8	31.0	30.4	29.5	28.2	26.6	24.5	21.8	19.3
8	29.5	28.2	27.8	27.0	25.8	24.3	22.5	20.0	17.7
10	27.5	26.7	25.8	25.0	23.8	22.3	20.5	18.5	16.3
12	25.7	24.8	24.0	23.0	21.9	20.5	19.0	17.0	15.0
14	24.0	23.2	21.4	20.4	19.1	17.7	16.7	15.7	13.7
16	22.5	21.7	20.9	20.0	19.0	17.9	16.5	14.6	12.6
18	21.3	20.5	19.6	18.7	17.8	16.7	15.4	13.5	11.5
20	20.2	19.4	18.5	17.6	16.7	15.6	14.4	12.5	10.5
22	19.2	18.5	17.5	16.5	15.7	14.7	13.5	11.6	9.9
24	18.3	17.5	16.5	15.6	14.9	14.0	12.7	11.0	9.0

ductivity. Experiments show that for $F_1/F_2 > 4.5$, i.e., for the formation of a bar with a smaller transverse cross section, for example, drain pipes or tiles, the productivity can be higher with lower rotational speed of the screw. In this case, the power expended decreases. This is explained by the fact that with a large difference of the areas F_1 and F_2 the resistance to pushing the mix through the mouthpiece increases sharply with a high rotational speed of the screw, while with a lower rotational speed the resistance is less of a factor.

The dependence of the optimal rotational speed of the screw shaft of the vacuum-press on the ratio F_1/F_2 for ceramic green mixes with normal (average) plasticity and moisture content 16 – 24% is presented in Fig. 4 and Table 2. For category-1 high-plasticity mixes the optimal rotational speed of the screw n_{opt} should be increased by 10%, and for category-3 low-plasticity clays it must be decreased by 12%. Intermediate values of F_1/F_2 and n_{opt} are determined by means of appropriate interpolation.

The packing factor of the molded mass, which depends on the specific compaction pressure, has a considerable effect on the change of productivity [2]. The higher the specific compaction pressure, the greater the packing factor is. In a number of cases the nominal productivity of the press can be increased substantially by transferring the press to operation with the optimal rotational speed of the screw shaft, which often differs significantly from the value established by the manufacturer of the press.

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